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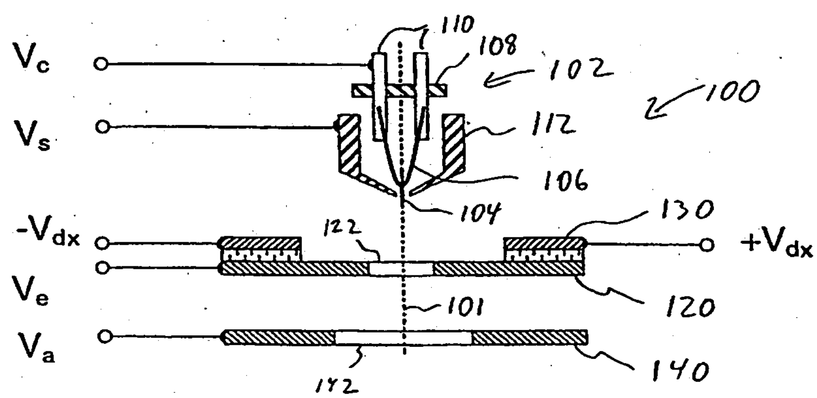
(54) Title: ELECTROSTATIC ALIGNMENT OF A CHARGED PARTICLE BEAM



(57) Abstract: A field emission source (100) produces a charged particle beam that can be electrostatically aligned with the optical axis. Quadrupole (or higher multipole) centering electrodes (130) approximately centered on the optical axis (101) are placed between the emitter (102) and the extraction electrode (120). By applying centering potentials of equal amplitude and opposite polarity on opposing elements of the centering electrodes, an electrostatic deflection field is created near the optical axis (101). The electrostatic deflection field aligns the charged particle beam with the optical axis thereby obviating the need to mechanically align the emitter with the optical axis. A second set of centering electrodes may be used to deflect the charged particle beam back and to ensure that the charged particle beam is parallel with the optical axis. Further, the extraction electrodes may be split into a quadrupole arrangement with the extraction and centering potentials superimposed.

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For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

ELECTROSTATIC ALIGNMENT OF A CHARGED PARTICLE BEAM

FIELD OF THE INVENTION

The present invention relates to a field emission source used, for example, in an electron beam microcolumn, and in particular to the electrostatic alignment of a charged particle beam.

BACKGROUND

Miniature electron beam microcolumns ("microcolumns") are based on microfabricated electron "optical" components and field emission sources operating under principles similar to scanning tunneling microscope ("STM") aided alignment principles. Field emission sources are bright electron sources that are very small, making them ideal for use in microcolumns. One type of field emission source is a Schottky emitter, such as the type discussed in

"Miniature Schottky Electron Source," H.S. Kim et al., Journal of Vacuum Science Technology Bulletin 13(6), pp. 2468-72, Nov./Dec. 1995 incorporated herein by reference. For additional field emission sources and for information relating to microcolumns in general, see the following publications and patents: "Experimental Evaluation of a 20x20 mm Footprint Microcolumn," by E. Kratschmer et al., Journal of Vacuum Science Technology Bulletin 14(6), pp. 3792-96, Nov./Dec. 1996; "Electron Beam Technology - SEM to Microcolumn," by T.H.P. Chang et al., Microelectronic Engineering 32, pp. 113-130, 1996; "Electron-Beam Microcolumns for Lithography and Related Applications," by T.H.P. Chang et al., Journal of Vacuum Science Technology Bulletin 14(6), pp. 3774-81, Nov./Dec. 1996; "Electron Beam Microcolumn Technology And Applications," by T.H.P. Chang et al., Electron-Beam Sources and Charged-Particle Optics, SPIE Vol. 2522, pp. 4-12, 1995; "Lens and Deflector Design for Microcolumns," by M.G.R. Thomson and T.H.P. Chang, Journal of Vacuum Science Technology Bulletin 13(6), pp. 2445-49, Nov./Dec. 1995; U.S. Pat. No. 5,122,663 to Chang et al.; and U.S. Pat. No. 5,155,412 to Chang et al., all of which are incorporated herein by reference.

Fig. 1 shows a schematic cross sectional view of a conventional field emission source 10, which includes an electron emitter 12 and an extraction electrode 14. The electron emitter 12 is a Schottky emitter with a tungsten tip 16 serving as a cathode, which is spot welded on a filament 18. The filament 18 is mounted on two rods 20, which are held by a base 22, and is surrounded by a suppressor cap 24.

The extraction electrode 14 defines a center aperture 15. The aperture 15 and following (downstream) lenses (not shown) in the microcolumn define the optical axis 26 for the field emission source 10.

By applying a voltage Vc to the tip 16 and a voltage Ve to the extraction electrode 14, a resulting electric field causes the emission of electrons from tip 16. A voltage Vs applied to the suppressor cap 24 suppresses undesired thermionic electrons.

An important consideration in the field emission source 10 is that the electron emitter 12 is aligned with the optical axis 26. Because the diameter of aperture 15 is typically 1-2 μm (micrometers), a small misalignment, e.g., 1 μm, will result in a large off-axis aberration and an undesirable increase in the

total spot size. Thus, a small misalignment can severely deteriorate the performance of a microcolumn.

Conventionally, to ensure proper alignment, the electron emitter 12 is mechanically aligned with the optical axis 26. Thus, electron emitter 12 is physically moved, as indicated by arrows 28, by the use of, e.g., alignment screws, a micrometer x-y stage, a piezoelectric stage, or a scanning tunneling microscope (STM) like positioner to align position electron emitter 12 with optical axis 26. Unfortunately, mechanical alignment is difficult to achieve and is difficult to maintain over extended periods of time due to drift problems.

Thus, there is a need for a field emission source that can be easily aligned with the optical axis.

SUMMARY

A field emission source in accordance with the present invention produces a charged particle beam that is electrostatically aligned with the optical axis. The field emission source includes a charged particle emitter, such as a Schottky or cold-field emitter. Centering electrodes define an aperture through which a beam of charged particles from the emitter passes and which is approximately centered on the optical axis.

The centering electrodes provide an electrostatic deflection field near the optical axis that aligns the beam of charged particles with the optical axis, i.e., the axis of the electron beam passes through the center of the next lens down stream. Thus the emitter need not be precisely aligned mechanically with the optical axis.

The center electrodes may be, for example, a quadrupole (or higher multipole) arrangement of electrodes placed between the emitter and an extraction electrode. By applying centering potentials of equal amplitude and opposite polarity on opposing elements of the centering electrodes, an electrostatic deflection field is created near the optical axis. The electrostatic deflection field aligns the charged particle beam with the optical axis thereby obviating the need to mechanically align the emitter with the optical axis. A second set of centering electrodes may be used to further deflect the charged particle beam and to ensure that the charged particle beam is approximately parallel with the optical axis. The centering electrodes may be integrally formed on the extraction electrode with an insulating layer between the extraction electrode and the centering electrodes and between the first set of centering electrodes and

the second set of centering electrodes if a second set is used.

In another embodiment, the extraction electrode is split into a quadrupole (or higher multipole) arrangement. The extraction potential and the centering potentials are then superimposed.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 shows a schematic cross sectional view of a conventional field emission source, which includes an electron emitter that is mechanically aligned with the optical axis as shown by arrow 28.

Fig. 2 shows a schematic cross sectional view of a field emission source including centering electrodes to electrostatically aligned an electron beam the optical axis in accordance with an embodiment of the present invention.

Fig. 3 shows a top view of the extraction electrode and centering electrodes.

Fig. 4 shows a schematic cross sectional view of the correction of an electron beam produced by a misaligned field emission source in accordance with the present invention.

Fig. 5 shows a schematic cross sectional view of a field emission source with two sets of centering

electrodes in accordance with another embodiment of the present invention.

Fig. 6 shows a schematic cross sectional view of the correction of an electron beam produced by a misaligned field emission source in accordance with another embodiment of the present invention.

Fig. 7 shows a schematic cross sectional view of a field emission source with centering extraction electrodes in accordance with another embodiment of the present invention.

Fig. 8 shows a top view of the centering extraction electrodes from Fig. 7.

DETAILED DESCRIPTION

Fig. 2 shows a schematic cross sectional view of a field emission source 100, with an electron emitter 102 and an extraction electrode 120 and including centering electrodes 130 to electrostatically align an electron beam with the optical axis 101 in accordance with an embodiment of the present invention.

The electron emitter 102 is a Schottky emitter with an etched single crystal tungsten tip 104, approximately 50-100 μm in diameter, that is spot-welded on a filament 106 such as a tungsten wire, approximately 50-100 μm in diameter. The filament 106

is mounted on a support structure, which includes a base 108, two rods 110, and a suppressor cap 112. The filament 106 is connected to the rods 110, which is supported by the base 106. Electron emitter 102 may also be a cold-field emitter as is well known in the art.

The electron emitter 102 is mounted in front (upstream) of the extraction electrode 120. The extraction electrode 120 defines a center aperture 122, which is approximately 1-2 μm diameter. Following extraction electrode 120 are the conventional lens structures of the microcolumn, which for the sake of simplicity are shown as a single lens electrode 140 defined by a lens aperture 142. The optical axis 101 is centered on the extraction electrode aperture 122 and the lens aperture 142.

The field emission source 100 electrostatically corrects any misalignment between the electron emitter 102 and the optical axis 101. Thus, the electron emitter 102 may be rigidly mounted with respect to optical axis 101 and only a coarse physical prealignment of the electron emitter 102 with the extraction electrode 120 is necessary. The prealignment is mechanically performed, for example, using a conventional flexure stage or inertial walker

during assembly. Advantageously, the electrostatic alignment in accordance with the present invention aligns the electron beam with the optical axis with the same or greater precision as with the conventional mechanical alignment. Thus, the necessity of extremely precise mechanical alignment is obviated.

In accordance with one embodiment of the present invention, the electrostatic alignment is achieved by electrostatic centering electrodes 130 positioned between the electron emitter 102 and the extraction electrode 120. Fig. 3 shows a top (plan) view of the extraction electrode 120 and electrostatic centering electrodes 130. As shown in Fig. 3, the centering electrodes 130 are in a quadrupole arrangement with electrode elements 130a, 130b, 130c, and 130d and approximately centered on optical axis 101. It should be understood that centering electrodes 130 may be a higher number multipole arrangement, e.g., an octopole or dodecapole.

The centering electrodes 130 are fabricated using the same micromachining technology used to fabricate lens components in a microcolumn, as is well understood by those of ordinary skill in the art. An electrically insulating layer 132 is deposited over the extraction electrode 120. The insulating layer 132 is for example

silicon dioxide, pyrex, or a similar material and is 0.5 to 20 μm thick. A conductive layer, such as aluminum, gold, silicon (that is heavily n doped), copper, platinum, or other conductive material, is then deposited over the insulating layer 132 to a thickness of 1-100 μm. The conductive layer is then lithographically patterned and etched to form the desired centering electrodes 130. The deposition, patterning and etching of a conductive layer is well understood by those of ordinary skill in the art.

To cause the emission of electrons, a voltage Vc is applied to the rods 110 of the electron emitter 102, while a voltage Vs is applied to the suppressor cap 112, and a voltage Ve is applied to the extraction electrode 120. The difference in potentials between the electron emitter 102 and the extraction electrode 120 (Vc-Ve) creates a strong electric field in the area of the tip 104, causing the emission of electrons. The temperature of the tip 104 is regulated to approximately 1700 to 1800 degrees K by a current passing through the filament 106, and the average power is 1.5-2.0 W.

Potentials are applied to the individual centering electrode elements 130a, 130b, 130c, and 130d to form a deflection field near the optical axis 101. The

deflection field approximately centers the emitted electron beam with respect to the optical axis, i.e., the axis of the electron beam passes through the center of the next lens down stream. Potentials of equal amplitude and opposite polarity are applied to opposite electrodes. Thus, for example, electrode element 130a will be at a voltage Vdx while electrode element 130c will be at a voltage -Vdx. Similarly, electrode element 130b will be at a voltage Vdy while electrode element 130d will be at a voltage -Vdy. The typical voltages used on the electrode elements range from a few tens of volts to a few hundred volts. If the electron emitter 102 is properly aligned with optical axis 101 and thus no centering potential is necessary, a uniform bias potential Vb may be applied to all individual electrode elements so that a uniform extraction field is preserved.

Fig. 4 shows a schematic cross sectional view of a misaligned field emission source 100 producing an electron beam 103 while centering electrodes 130 electrostatically align the electron beam 103 with the optical axis 101. As shown in Fig. 4, without the centering potential produced by centering electrodes 130, an electron beam would be misaligned with the optical axis (as indicated by the broken lines 103a).

By application of centering potential on centering electrodes 130, an electrostatic deflection field is generated (as indicated by arrow 131), which deflects the electron beam 103 so that it is in approximate alignment with the optical axis 101, i.e., the axis of the electron beam passes through the center of the next lens down stream (not shown in Fig. 4).

The centering process may result in a small tilt of the electron beam 103 with respect to the optical axis 101, as shown in Fig. 4. The centering systems in the lenses that follow the extraction electrode 120, e.g., lens 140 shown in Fig. 2, may compensate for any residual tilt.

Fig. 5 shows a schematic cross sectional view of a field emission source 200 in accordance with another embodiment of the present invention. Field emission source 200 is similar to field emission source 100, shown in Fig. 2, like designated elements being the same, however, field emission source 200 includes a second set of electrostatic centering electrodes 210 follow centering electrodes 130. The second set of centering electrodes 210 are similar in fabrication and operation to centering electrodes 130. The second set of centering electrodes 210 are used to allow simultaneous beam translation and parallelism to the

optical axis thereby removing the residual tilt generated by centering electrodes 130 (which is illustrated in Fig. 4).

Centering electrodes 210 are fabricated in a manner similar to centering electrodes 130. An insulating layer 212 of approximately 0.5 to 20 μm is deposited over the extraction electrode 120. A conductive layer that forms the second set of centering electrodes 210 is deposited over the insulating layer 212. Another insulating layer 130, similar to insulating layer 212 is then deposited followed by another conductive layer that forms the first set of centering electrodes 130. The stack of conductive layers and insulating layers is then lithographically patterned and etched to define the desired centering electrodes 130 and second set of centering electrodes 210. Of course, if desired additional sets of centering electrodes may be produced in a similar manner.

Fig. 6 shows a schematic cross sectional view of a misaligned field emission source 200 producing an electron beam 203 while centering electrodes 130 and a second set of centering electrodes 210 electrostatically align the electron beam 203 with the optical axis 101. As shown in Fig. 6, by application

of centering potential on centering electrodes 130, a first electrostatic deflection field is generated (as indicated by arrow 231), which deflects the electron beam 203 so that it is in approximate alignment with the optical axis 101, i.e., the axis of the electron beam 203 passes through the center of the centering electrodes 210. The applied centering potentials are of equal amplitude and opposite polarity for opposite electrodes, i.e., ±Vdx1 and ±Vdy1 (which is applied to the centering electrode elements not shown in the cross sectional view of Figs. 5 and 6).

By application of a second centering potential on the second set of centering electrodes 210, a second electrostatic deflection field is generated (as indicated by arrow 232), which deflects the electron beam 203 in a direction opposite to the direction that the electron beam 203 was deflected by centering electrodes 130. The second set of centering potentials are applied to opposite electrodes of the second set of centering electrodes 210, i.e., ±Vdx2 and ±Vdy2 (which is applied to the centering electrode elements not shown in the cross sectional view of Figs. 5 and 6). As shown in Fig. 6, the orientations of the deflection fields generated by the two sets of deflection electrodes 130 and 210 are opposite in direction. The

second set of potentials applied to centering electrodes 210 removes residual tilt created by centering electrodes 130, thereby deflecting the electron beam 203 to be approximately parallel with the optical axis 101, e.g., within 3 milliradians. A bias potential Vb may be applied to one or both sets of centering electrodes 130 and 210 so that a uniform extraction field is preserved if no electrostatic alignment is necessary.

Fig. 7 shows a schematic cross sectional view of a field emission source 300 in accordance with another embodiment of the present invention. Field emission source 300 is similar to field emission source 100, shown in Fig. 2, like designated elements being the same, however, the extraction electrode 120 and the centering electrodes 130 are replaced with a centering extraction electrode 310.

Fig. 8 shows a top view of the centering extraction electrode 310. As shown in Fig. 8, the centering extraction electrodes 310 is an extraction electrode split into a quadrupole arrangement having electrode elements 310a, 310b, 310c, and 310d. Of course, centering extraction electrode 310 may have a higher multipole arrangement if desired.

The centering extraction electrodes 310 operate as both the extraction electrode and the centering electrode. As shown in Figs. 6 and 7, the extraction potential Ve and the centering potentials ±Vdx and ±Vdy are superimposed on the individual elements of the centering extraction electrodes 310.

The centering extraction electrodes 310 are fabricated using the same micromachining silicon technology used to fabricate lens components in a microcolumn, as is well understood by those skilled in the art. If desired, centering extraction electrodes 310 may be fabricated on a substrate (not shown), such as a silicon substrate, which may aid in the prevention of warping or mechanical breakdown of the centering extraction electrodes 310.

While the present invention has been described in connection with specific embodiments, variations of these embodiments will be obvious to those of ordinary skill in the art in light of the present disclosure. Thus, for example, while the present disclosure describes a field emission source in accordance with the present invention as including an electron emitter, it should be understood that any charged particle, including positive ions may be emitted and electrostatically aligned in accordance with the

present invention. Therefore, the spirit and scope of the appended claims should not be limited to the foregoing description.

CLAIMS

What is claimed is:

1. A field emission source comprising:

a charged particle emitter, said charged particle emitter emitting a beam of charged particles;

at least four centering electrode elements defining a central aperture that is approximately centered on an optical axis, whereby said beam of charged particles passes through said central aperture, and wherein said at least four centering electrode elements generate an electrostatic deflection field thereby to align said beam of charged particles with said optical axis.

2. The field emission source of Claim 1, further comprising:

an extraction electrode defining an aperture approximately centered on said optical axis;

wherein said at least four centering electrode elements are positioned between said charged particle emitter and said extraction electrode.

3. The field emission source of Claim 2, wherein said at least four centering electrode elements are integrally formed on said extraction electrode with an insulating layer between said extraction electrode and said at least four centering electrode elements.

4. The field emission source of Claim 1, wherein said at least four centering electrode elements are extraction electrode elements that produce an extraction potential.

5. The field emission source of Claim 1, wherein said charged particle emitter is an electron emitter and said beam of charged particles is an electron beam.

6. The field emission source of Claim 5, wherein said electron emitter is at least one of a Schottky emitter or a cold-field emitter.

7. The field emission source of Claim 1, further comprising:

a second set of at least four centering electrode elements defining a second aperture that is approximately centered on said optical axis, whereby said beam of charged particles passes

through said second aperture, wherein said second set of at least four centering electrode elements generate a second electrostatic deflection field thereby to deflect said beam of charged particles to be approximately parallel with said optical axis after said beam passes through said at least four centering electrode elements and said second set of at least four centering electrode elements.

8. The field emission source of Claim 7, wherein said at least four centering electrode elements and said second set of at least four centering electrode elements are integrally formed on said extraction electrode with a first insulating layer between said at least four centering electrode elements and said second set of at least four centering electrode elements and a second insulating between said extraction electrode and said second set of at least four centering electrode elements.

9. A method of aligning a charged particle beam with an optical axis, said method comprising:

providing an extraction field to produce a charged particle beam;

providing an electrostatic deflection field near said optical axis, wherein said electrostatic deflection field deflects said charged particle beam to be in alignment with said optical axis.

10. The method of Claim 9, wherein said providing an extraction field comprises:

applying a first voltage on a charged particle emitter; and

applying a second voltage on an extraction electrode;

wherein said extraction field is the difference between said first voltage and said second voltage.

11. The method of Claim 9, wherein said providing an electrostatic deflection field near said optical axis comprises:

applying a first centering voltage on a first centering electrode on a first side of said optical axis; and

applying a second centering voltage on a second centering electrode on a second side of said optical axis, said second side being opposite said first side relative to said optical axis;

wherein said first centering voltage and said second centering voltage are equal in amplitude and opposite in polarity.

12. The method of Claim 11, wherein said providing an electrostatic deflection field near said optical axis further comprises:

applying a third centering voltage on a third centering electrode on a third side of said optical axis; and

applying a fourth centering voltage on a fourth centering electrode on a fourth side of said optical axis, said fourth side being opposite said third side relative to said optical axis;

wherein said third centering voltage and said fourth centering voltage are approximately equal in amplitude and opposite in polarity.

13. The method of Claim 9 wherein providing an extraction field and providing an electrostatic deflection field comprises:

applying a first voltage to a first electrode on a first side of said optical axis, said first voltage being equal to the sum of an extraction voltage and a first centering voltage; and

applying a second voltage to a second electrode on a second side of said optical axis, said second side being opposite said first side relative to said optical axis, said second voltage being equal to the sum of said extraction voltage and a second centering voltage;

wherein said first centering voltage and said second centering voltage are equal in amplitude and opposite in polarity.

14. The method of Claim 13 wherein providing an extraction field and providing an electrostatic deflection field comprises:

applying a third voltage to a third electrode on a third side of said optical axis, said third voltage being equal to the sum of an extraction voltage and a third centering voltage; and

applying a fourth voltage to a fourth electrode on a fourth side of said optical axis, said fourth side being opposite said third side relative to said optical axis, said fourth voltage being equal to the sum of said extraction voltage and a fourth centering voltage;

wherein said third centering voltage and said fourth centering voltage are equal in amplitude and opposite in polarity.

15. The method of Claim 9, further comprising:

providing a second electrostatic deflection field near said optical axis, wherein said second electrostatic deflection field deflects said charged particle beam to be approximately parallel to said optical axis.

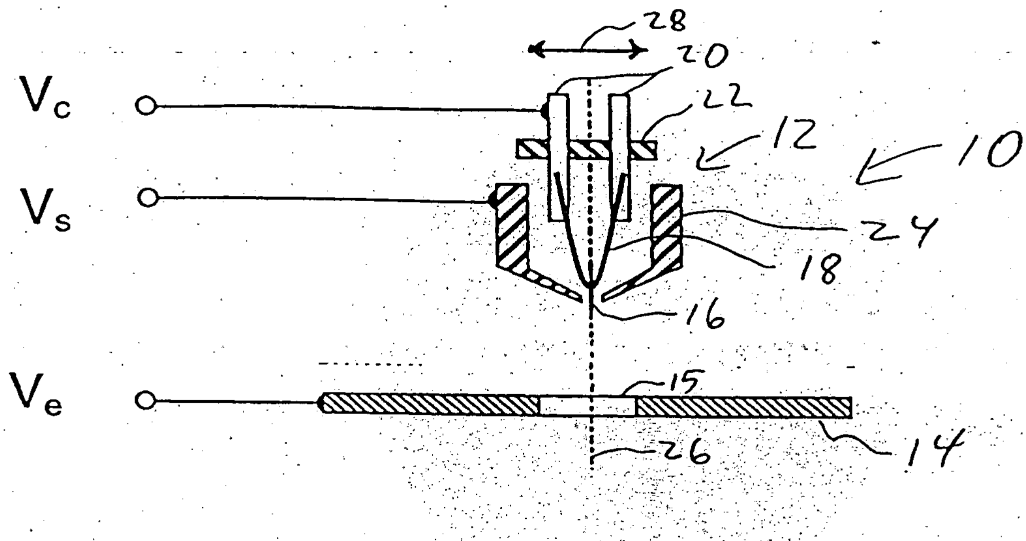


Fig 1 (Prior Art)

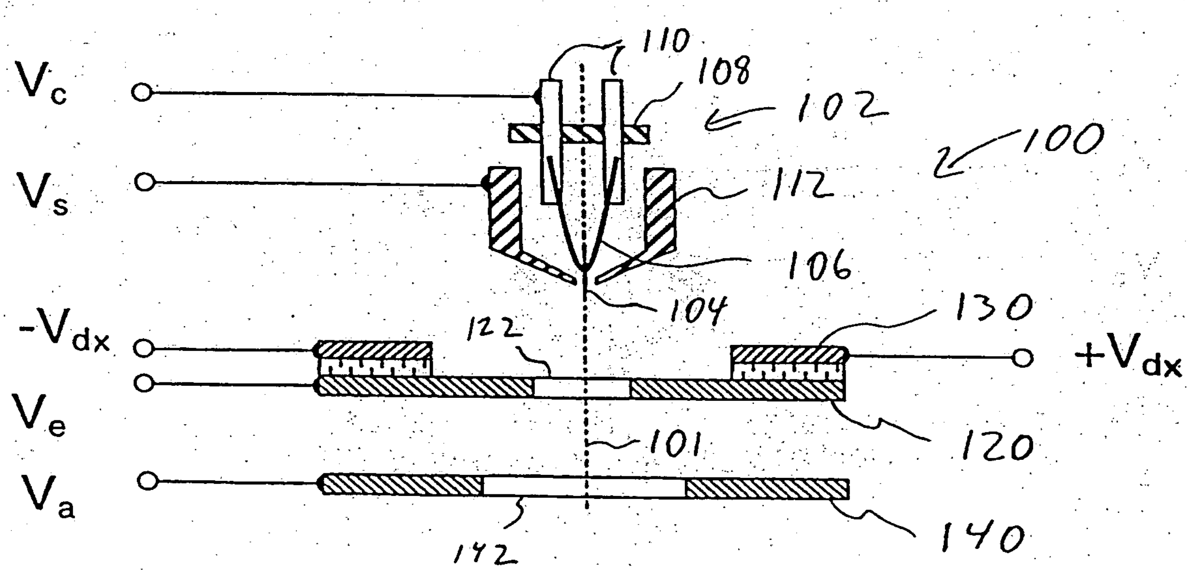


Fig 2

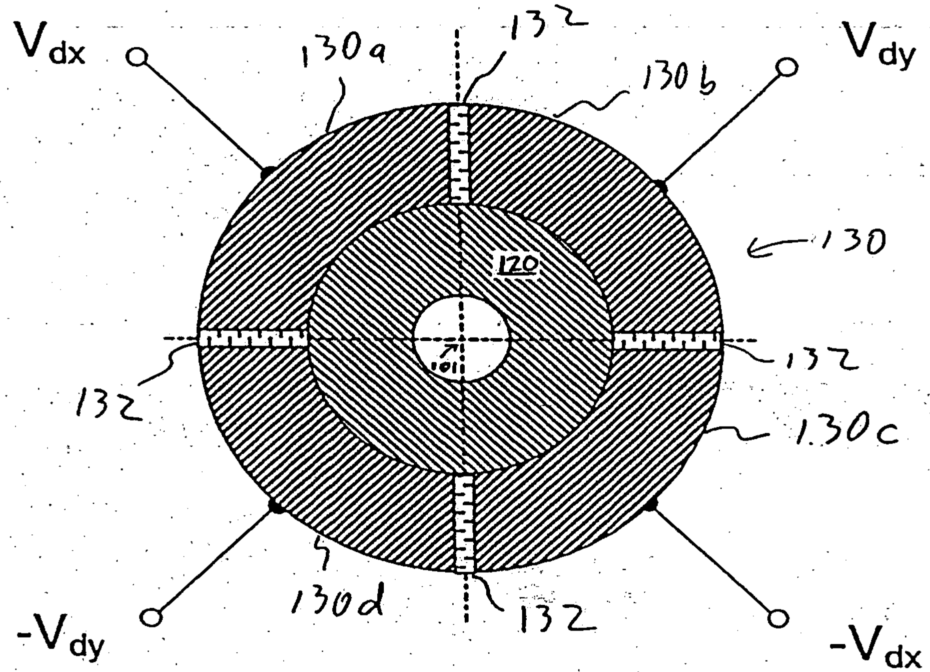

Vdx
130a
132
130b
Vdy
130
120
101
132
132
130c
130d
132
-Vdy
-Vdx

Fig 3

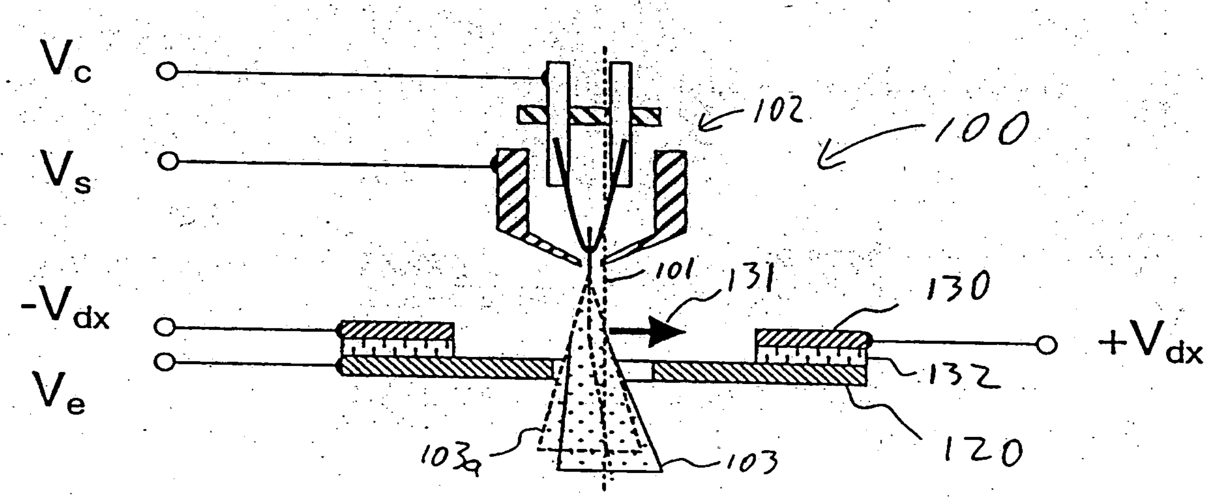
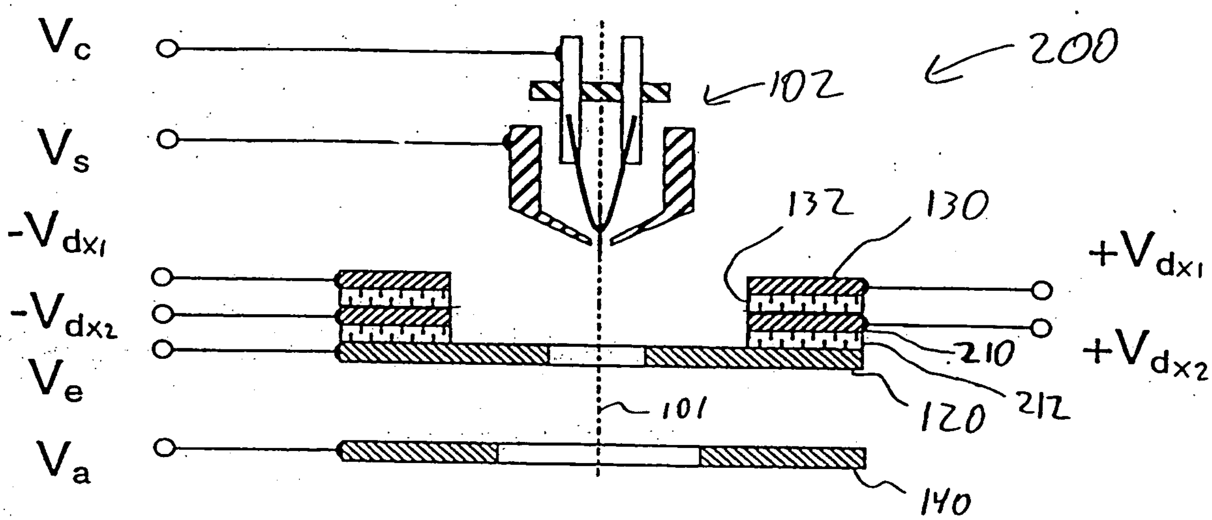
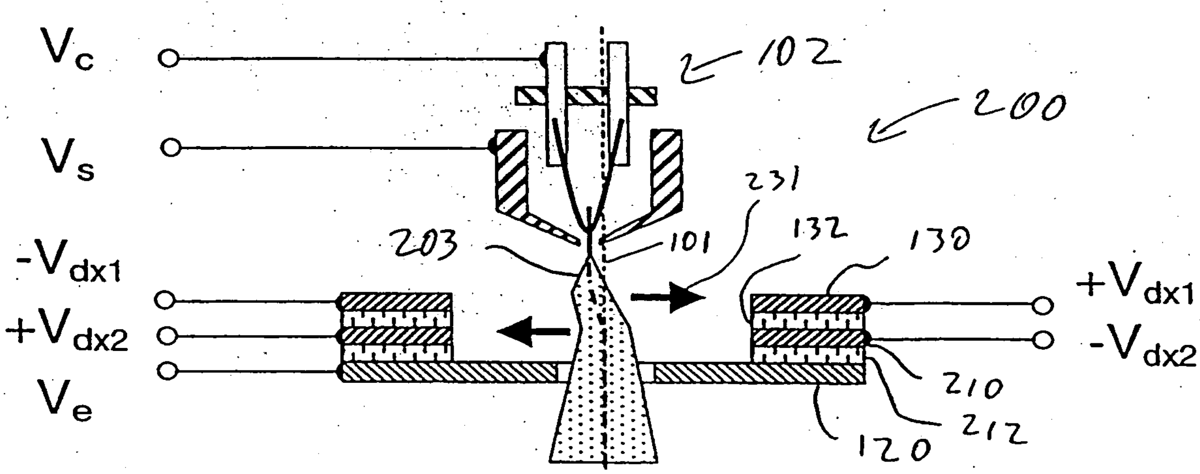

Vc
102
100
Vs
101
131
130
-Vdx
+Vdx
Ve
132
120
103a
103

Fig 4



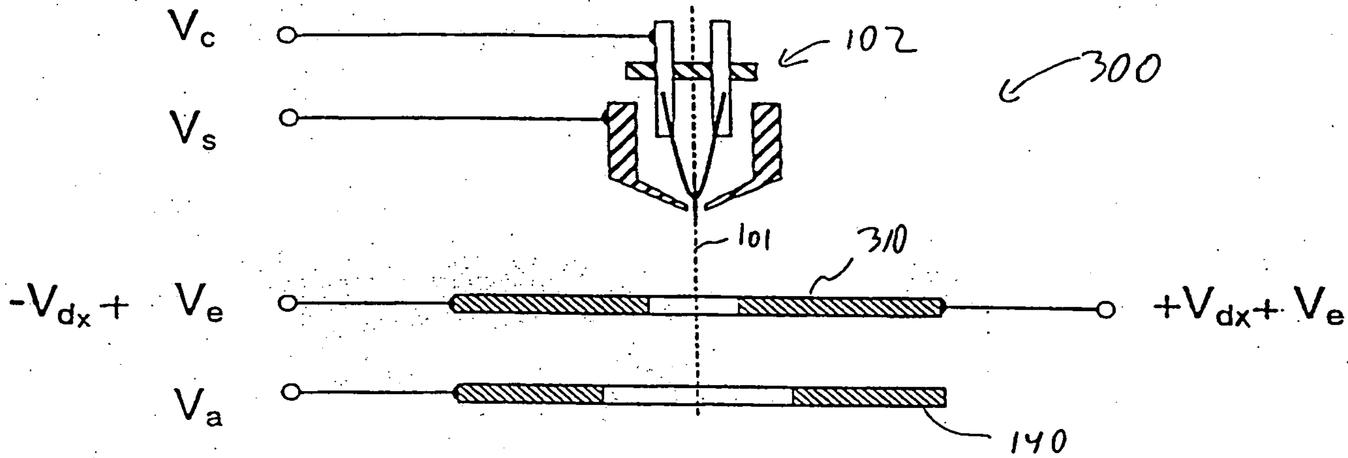
Vc
Vs
-Vdx1
-Vdx2
Ve
Va
102
200
132
130
+Vdx1
+Vdx2
210
212
120
101
140

Fig 5



Vc
Vs
-Vdx1
+Vdx2
Ve
102
200
231
203
101
132
130
+Vdx1
-Vdx2
210
212
120

Fig 6


Vc
Vs
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300
101
310
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$+V_{dx}+V_e$
V_a
140

Fig 7

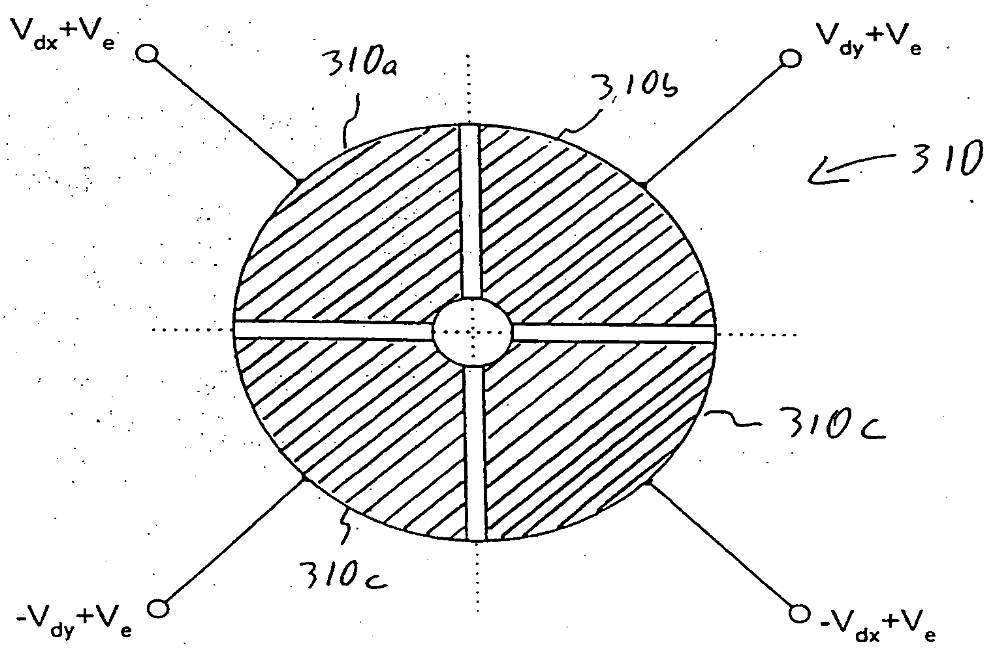
$V_{dx}+V_e$
$V_{dy}+V_e$
310a
310b
310
310c
310c
$-V_{dy}+V_e$
$-V_{dx}+V_e$

Fig 8

INTERNATIONAL SEARCH REPORT

Interr. .nal Application No
PCT/US 00/40463

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 H01J37/147 H01J29/54

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 H01J

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

PAJ, WPI Data, EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 3 358 174 A (W.E.GLENN) 12 December 1967 (1967-12-12) column 3, line 5 -column 4 ---	1,9,11, 15
X	US 3 548 250 A (ROOSMALEN JOHANNES HENDRIKUS T ET AL) 15 December 1970 (1970-12-15) column 5, line 65 -column 7 ---	1
P,X	WO 00 24030 A (ETEC SYSTEMS INC) 27 April 2000 (2000-04-27) claims 1-15 ---	1,9
X	DE 32 05 027 A (SIEMENS AG) 25 August 1983 (1983-08-25) claims 1-13; figure 3 --- -/--	1

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
7 December 2000	14/12/2000

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